Riverbank Filtration as a Sustainable Solution for Drinking Water Quality and Quantity Problems in Haridwar, Uttarakhand

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Abstract

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ABSTRACT: Riverbank filtration (RBF) is an efficient and low-cost natural alternative technology for water supply application, in which surface water contaminants are removed or degraded as the infiltrating water moves from the river/lake to the pumping wells. The removal or degradation of contaminants is a combination of physicochemical and biological processes. This paper presents an investigation to the full setup of 22 RBF large diameter (10m) caisson wells located along the bank of river Ganga in order to supply portable drinking water for Haridwar (112617 persons residing permanently in the main city). These 22 RBF large diameter (10m) caisson wells were constructed along the bank of river Ganga at Haridwar, each 7-10m deep and are located 50 – 450 m from the Ganga River or the Upper Ganga Canal. Water samples from river Ganga as induced surface water, from Upper Ganga Canal (UGC), groundwater(open well), and from RBF wells were collected and analyzed for premonsoon and postmonsoon period. Quality measurements of physical, chemical, and microbiological characteristics were obtained. Comparison of water supplied from RBF wells with surface, UGC and background natural groundwater for the investigated Haridwar site has proven the effectiveness of RBF technique for potable water supply in Haridwar district of Uttarakhand. Physicochemical and microbiological characteristics of the produced water are better than the allowable standards (IS 10500) for drinking purposes or recommended WHO limits. The results prove the implementation of RBF treatment method as advanced technique for water supply and management in Haridwar.

INTRODUCTION

As the World's growing population puts greater demands on the available supply of high quality drinking water, several advanced treatment technologies have been developed and applied by water utilities to treat waters of degraded quality. These technologies include adsorption, ion exchange, membrane filtration, soil aquifer treatment and advanced oxidation. Notwithstanding the effectiveness of these technologies, there are challenges for their widespread applications in developing countries. This is primarily attributed to cost (especially for treating large quantities). In this context, an old method called riverbank filtration (RBF) is returning and evolving as an inexpensive and a sustainable approach to improving the quality of surface waters. (Shamrukh et al, 2008). Riverbank Filtration is natural pre-treatment technology where the water is extracted from wells instead of direct surface water abstraction from the river. The underground passage has several advantages, which are useful for drinking water treatment. The underground passage removes particles, bacteria, viruses, parasites and biodegradable compounds etc. It is well known that river water is characterized by extreme varying concentrations, depending on the water flow, seasonal effects, emissions by municipal and industrial sewage, runoff etc. However, concentration peaks are compensated and blended during an underground passage. This is due to different retention times, required for the water particles to flow from the river bottom through the underground to a well or to the different porosity of the soil. Therefore, the underground passage acts as a barrier against shock loads, caused from emergency situations such as defects in industrial wastewater plants. The compensation of temperature peaks will improve the water quality, too. This treatment technique is currently being used in Europe along the Rhine, Danube, Elbe, and Seine rivers (Kuehn and Mueller 2000; Doussan et al. 1997). Along the Rhine, there is one of the first RBF plants in Du¨sseldorf, Germany, to supply drinking water to a population of about 600,000 (Schubert 2002).In India, RBF technology is being implemented in Haridwar, Satpuli, Agastmuni, Srinagar, Karanprayag, Nainital and Delhi(Ghosh et al,2015).

Riverbank filtration is typically conducted in alluvial valley aquifers, which are complex hydrologic systems that exhibit both physical and geochemical heterogeneity. During RBF, which is similar to slow-sand filtration, the impurities of river water are attenuated through combination treatment processes. The performance of RBF systems depends upon well type and pumping rate, travel time of surface water to wells, site hydrogeologic conditions, source water quality, biogeochemical reactions in sediments and aquifer, and quality of background groundwater (Schijven et al. 2002; Ray 2001).

STUDY AREA DESCRIPTION

The bottom-entry caisson wells (RBF) are 7 – 10 m deep and are located 50 – 450 m from the Ganga River or the Upper Ganga Canal. As of April 2011, at least 12 wells operated continuously (24 hours), with the remaining wells operating for 9 – 19 hours per day. Each well usually has 2 – 3 fixed-speed vertical line shaft pumps, with each pump having a rated discharge of 600 – 2820 litres per minute (LPM), with a mean rated discharge of 1620 for all pumps. However, the pumps operate on a rotational basis for a fixed number of hours each day, which is necessary for the other pump(s) to cool and avoid malfunctions. Usually during the summer (pre-monsoon) and during religious festivals, the wells operate continuously as the demand for drinking water peaks. At other times only some wells operate continuously. The abstracted water is chlorinated at the wells and then supplied directly into the distribution network. The shortest travel time of bank filtrate to the RBF wells located on Pantdweep Island < 15 m from the bank of the surface water body is 2 days to > 100 days for wells located further away.

Haridwar is one of the very important Hindu pilgrimage sites of the world. The city, situated along the right bank of the river Ganga, has population of approximately 225,235 (Census of India 2011). More than 50% (> 64,000 m^3/day) of drinking water requirement of the city is supplied by 22 RBF wells. Each RBF well is equipped with a pump set above the ground surface and extracts water by a suction pipe of 15 cm diameter. Some have been constructed as a tube well in the caisson well. The tube wells have an aquifer penetration depth of about 5-6 m below the bottom of the caisson well. The discharge of the pumps ranges from 72 to 170 m^3/hr and the operating hours of these wells vary from one season to another between 10 and 24 hours continuously in a day. A schematic diagram of a RBF wells in Haridwar is shown in Fig. 1. The wells tap the unconfined aquifer of average thickness about 21 m hydraulically connected with the river/canal. Being located in the vicinity of the canal and river network, the wells when pumped induce water from both river and canal at varying rates depending upon the distance of the wells from them.

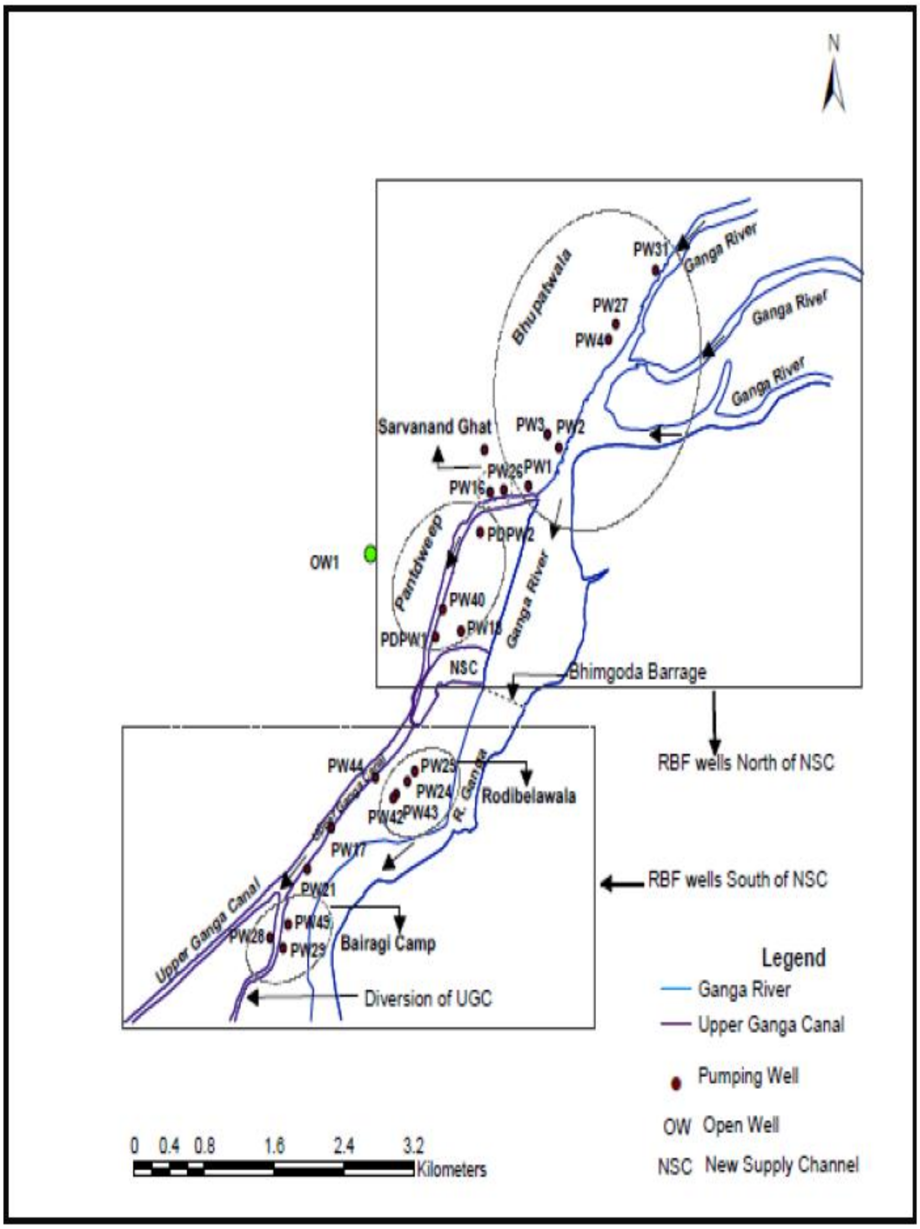

Figure 1: Study area representing setting of 22 Riverbank Filtration Wells in the vicinity of the river Ganga and Upper Ganga Canal (UGC) at Haridwar. (dots also indicate sampling points)

HYDROGEOLOGICAL SETTINGS

The study area falls under the north eastern part of Haridwar district which comprises of boulders, pebbles, gravels, sand and clay indicating good recharge zone. Aquifer type is unconfined ranging (3-21m) on which the 22 shallower bottom entry caisson (RBF) wells are located to pump out water for water supply. The tapping zone of all the 22 RBF wells lies within the unconfined aquifer between depth of 8 m and 14 m below the ground surface. Most of the wells have penetrated the aquifer partially, and maintain a considerable gap between the well-bottom and the underneath impervious strata. The hydrogeological formations represented by this unconfined aquifer have a very good hydraulic properties representing hydraulic conductivity (K) value range of 16-50 m/day (Dash et al., 2010).

MATERIAL AND METHOD

27 Water samples were collected from 22 wells, River Ganga (upstream and downstream), Upper Ganga canal (UGC) and groundwater from Haridwar RBF site. Samples were collected in polyethylene bottles preserved by adding an appropriate reagent (Jain and Bhatia, 1988; APHA, 1992) and analysed for various water quality parameters as per standard procedures (table1) for monsoon and non-monsoon period. The experimental values were compared with standard values recommended by WHO or Indian standards for drinking purposes. Comparison between water samples from RBF wells with River Ganga, UGC and groundwater samples was carried out to indicate the effectiveness of RBF technique for potable water supply in Haridwar district of Uttarakhand.

Water Sampling and Detailed Methodology:

1.0 EXPERIMENTAL METHODOLOGY

- 1.1 Sampling and Preservation
- 1.2 Chemicals and Reagents
- 1.3 Physico-chemical and Bacteriological Analysis
- 1.4 Metal Ion Analysis

1.1 Sampling and Preservation

Water samples were collected from various abstraction wells and River Ganga in clean polyethylene bottles preserved by adding an appropriate reagent (Jain and Bhatia, 1988; APHA, 1992). The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra-pure nitric acid (5 mL/lit.) Samples for bacteriological analysis were collected in sterilized high density polypropylene bottles covered with aluminium foils. All the samples were stored in sampling kits maintained at 4^{o}C and brought to the laboratory for detailed chemical and bacteriological analysis.

1.2 Chemicals and Reagents

All general chemicals used in the study were of analytical reagent grade (Merck/BDH). Standard solutions of metal ions were procured from Merck, Germany. Bacteriological reagents were obtained from HiMedia. De-ionized water was used throughout the study. All glassware and other containers used for trace element analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 h and finally rinsed with de-ionized water several times prior to use. All glassware and reagents used for bacteriological analysis were thoroughly cleaned and sterilized before use.

1.3 Physico-chemical and Bacteriological Analysis

The physico-chemical and bacteriological analysis was performed following standard methods (Jain and Bhatia, 1988; APHA, 1992). The brief details of analytical methods and equipment used in the study are given in Table 1. Ionic balance was determined; the error in the ionic balance for majority of the samples was within 5%.

1.4 Metal Ion Analysis

Metal ion concentrations were determined by atomic absorption spectrometry using Perkin Elmer Atomic Absorption Spectrometer (Model 3110) using air-acetylene flame. Operational conditions were adjusted in accordance with the manufacturer's guidelines to yield optimal determination. Quantification of metals was based upon calibration curves of standard solutions of respective metals. These calibration curves were determined several times during the period of analysis. The detection limits for iron and manganese are 0.003 and 0.001 respectively.

Table 1. Analytical Methods and Equipment Used in the Analysis

S.No.	**Parameter**	**Method**	**Equipment**
A.	**Physico-chemical**		
1.	pH	Electrometric	pH Meter
2.	Conductivity	Electrometric	Conductivity Meter
3.	TDS	Electrometric	Conductivity/TDS Meter
4.	Turbidity	Turbid metric	Turbidity Meter
5.	Alkalinity	Titration by H_2SO_4	-
6.	Hardness	Titration by EDTA	-
7.	Chloride	Titration by $AgNO_3$	-
8.	Sulphate	Turbid metric	Turbidity Meter
9.	Nitrate	Ultraviolet screening	UV-VIS Spectrophotometer
10.	Sodium	Flame emission	Flame Photometer
11.	Potassium	Flame emission	Flame Photometer
12.	Calcium	Titration by EDTA	-
13.	Magnesium	Titration by EDTA	-
14.	BOD	5 days incubation at 20^{o}C	BOD Incubator

		followed by titration	
15.	COD	Digestion followed by titration	COD Digestor
B	**Bacteriological**		
16.	Total coliform	Membrane Filtration (MF) technique	Filtration Assembly, Bacteriological Incubator
17.	Faecal coliform		
C.	**Heavy Metals**		
18.	Iron	Digestion followed by Atomic Spectrometry	Atomic Absorption Spectrometer
19.	Manganese		

WATER QUALITY ANALYSIS OF PHYSICOCHEMICAL AND BACTERIOLOGICAL PARAMETERS

To determine the water quality improvement of riverbank filtrate, samples of the surface, groundwater and the RBF well water have been collected once a month continuously for two years. Comparing different water quality parameters for surface, ground and pumping well water samples enabled the assessment of the natural treatment process of riverbank filtrate, when passing the subsurface. As per the physical process of bank filtration, during pumping, the induced bank filtrate from river water after mixing with the groundwater gets withdrawn, which leads to modification of quality of bank filtrate water by the quality of groundwater. Thus, the quality of extracted water depends on mixing proportion of groundwater with the bank filtrate water.

Compared results of water quality parameters for surface and groundwater, and pumping (RBF) well showed considerable improvement in the quality of riverbank filtrate water as it moves through the subsurface. Analyses of major ions such as, **Na^{2+}, K+, Ca^{2+}, Mg^{2+}, SO_4^{2-} and NO_3^-** enabled to understand the mineralization process of water during the subsurface passage. Concentration graph showing the major ions present in surface, groundwater and pumping well has been plotted to depict the same for Bhupatwala, Pantdweep and Beragi Camp area. Ca^{2+} concentration is high in Bhupatwala and Pantdweep as influenced by already mineralized groundwater whereas Bairagi camp has low Ca^{2+} concentration due to its near proximity to canal or surface water (Figure 3).

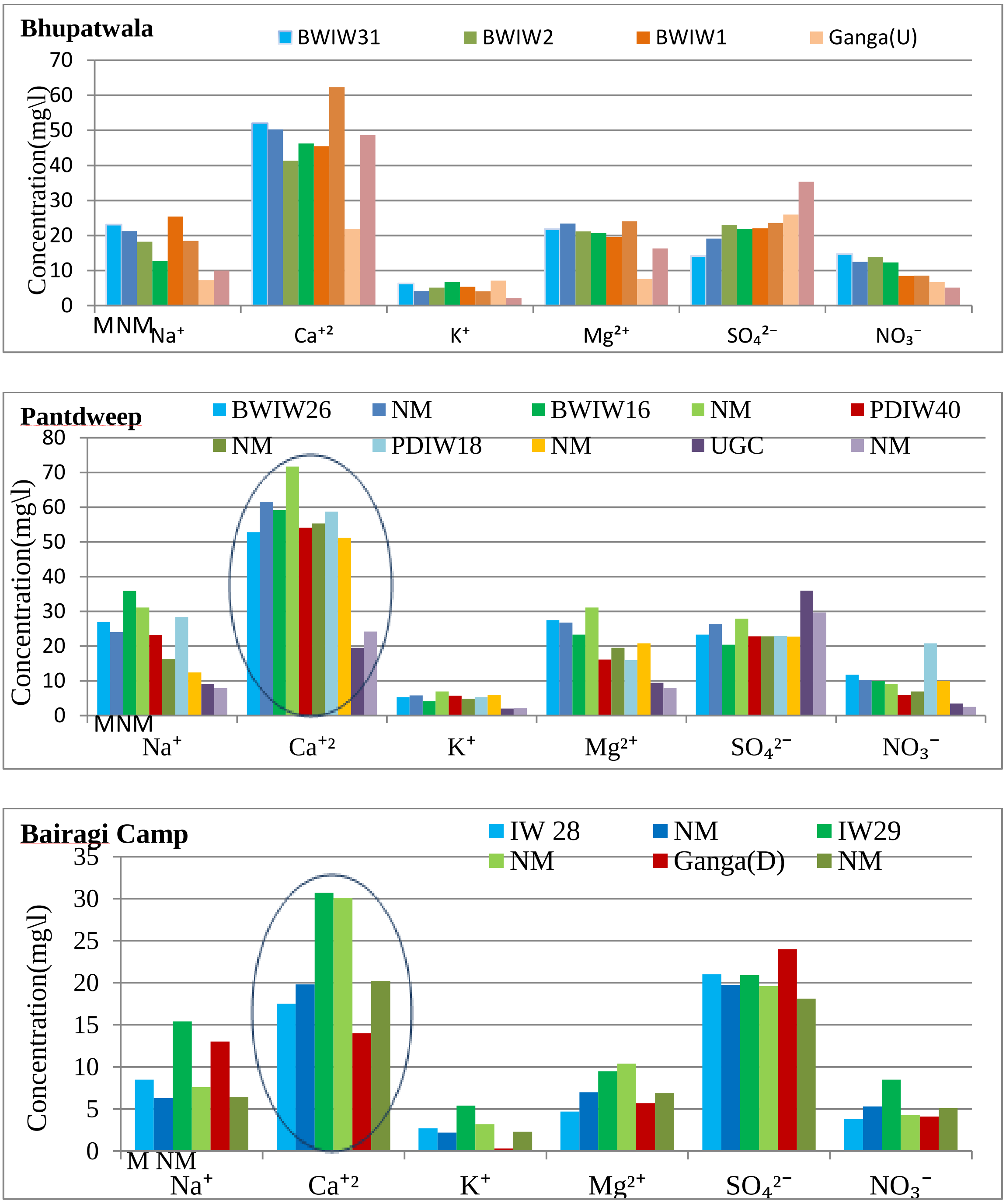

Figure 2. Concentration Plot of major ions present in Pumping wells and River Ganga

Ferrous and Manganese are essential dietary element present in water and according to WHO(2011) the recommended health based limit values for Fe^{2+} and Mn^{2+} are 2 mg/L and 0.4 mg/L, respectively. Concentration plot for Ferrous and Manganese present in River and nearby RBF wells for Bhupatwala, Pantdweep and Bairagi camp depict that surface water is having higher concentration of Ferrous and Manganese ranging from 2.1 to 5.5 mg/L and from 1.9 to 6.7 mg/L, respectively, during monsoon as higher discharge and flow velocities cause erosion of Fe^{2+} and Mn^{2+} which is accumulated in riverbed during low flow in river (Figure 4).

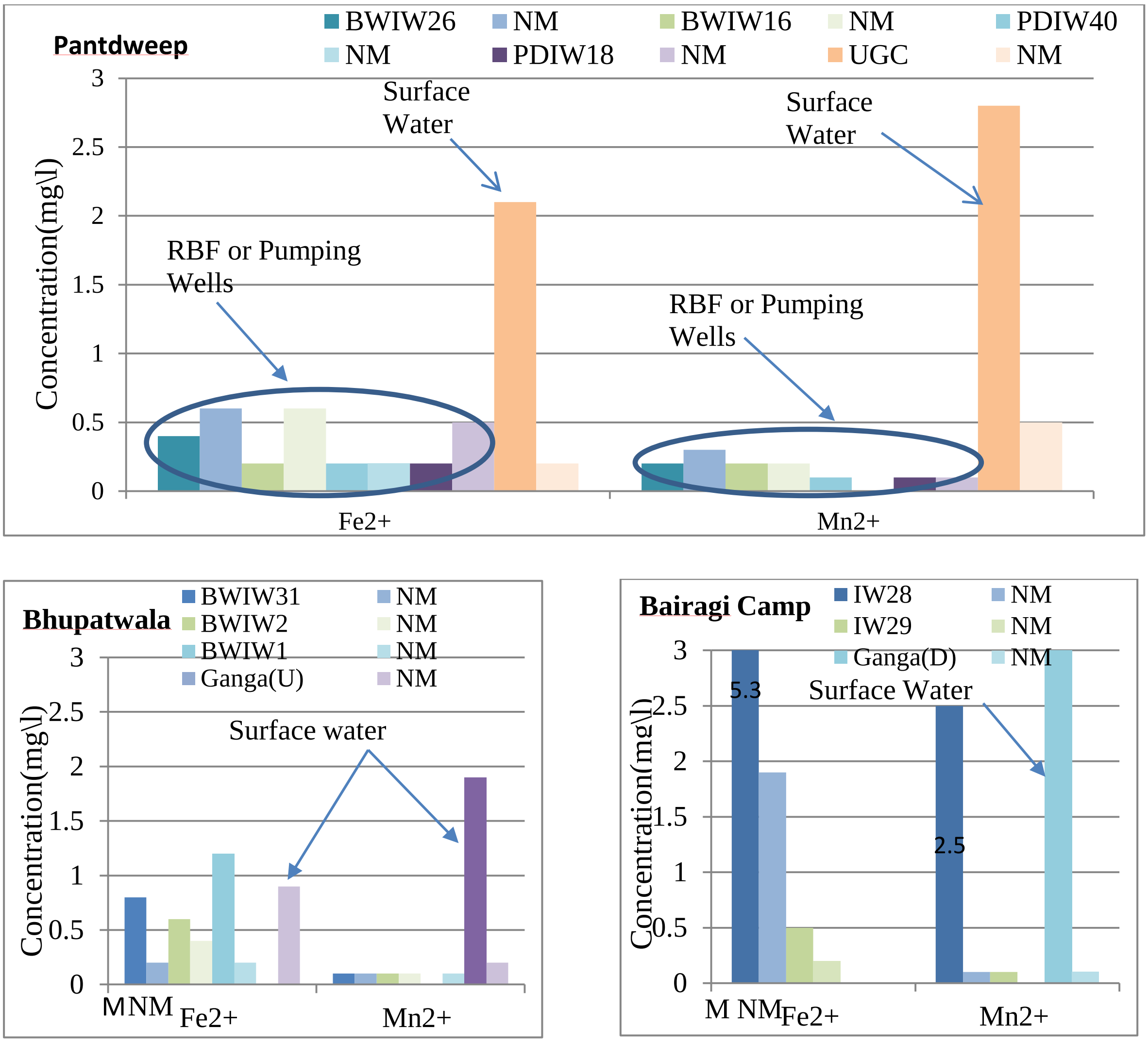

Figure 3. Concentration Plot of Ferrous and manganese present in Pumping wells and river Ganga

Turbidity is the measure of relative clarity of a liquid. Material that causes water to be turbid includes clay, silt, finely divided inorganic and organic matter, algae, soluble colour organic compounds, and plankton and other microscopic organisms. The most important health-related function of turbidity is its use as an indicator of the effectiveness of drinking water treatment processes, particularly filtration, in the removal of potential microbial pathogens. There is no precise relationship between the magnitude of turbidity reduction and the removal of pathogens. Compared to groundwater, the turbidity within rivers is mostly higher due to higher flow velocities, which causes erosion of bed-material. Microorganisms are typically attached to particulates and removal of turbidity by riverbank filtration will significantly reduce microbial contamination within water. Turbidity also affects the selection and efficiency of treatment processes, particularly the efficiency of disinfection with chlorine since it exerts a chlorine demand and protects microorganisms and may also stimulate the growth of bacteria (WHO 2011). Turbidity result is visualized in Figure 4 which shows that the turbidity of Ganga River (upstream and downstream of Bhimgoda barrage) is 2 to 15 times more turbid in monsoon season due to high flow velocities, high runoff and erosion of soil and riverbed materials respectively. The turbidity of the abstracted water from RBF wells is below the Indian Standard limit of 5 NTU (IS 10500, 1993) during monsoon and non-monsoon.

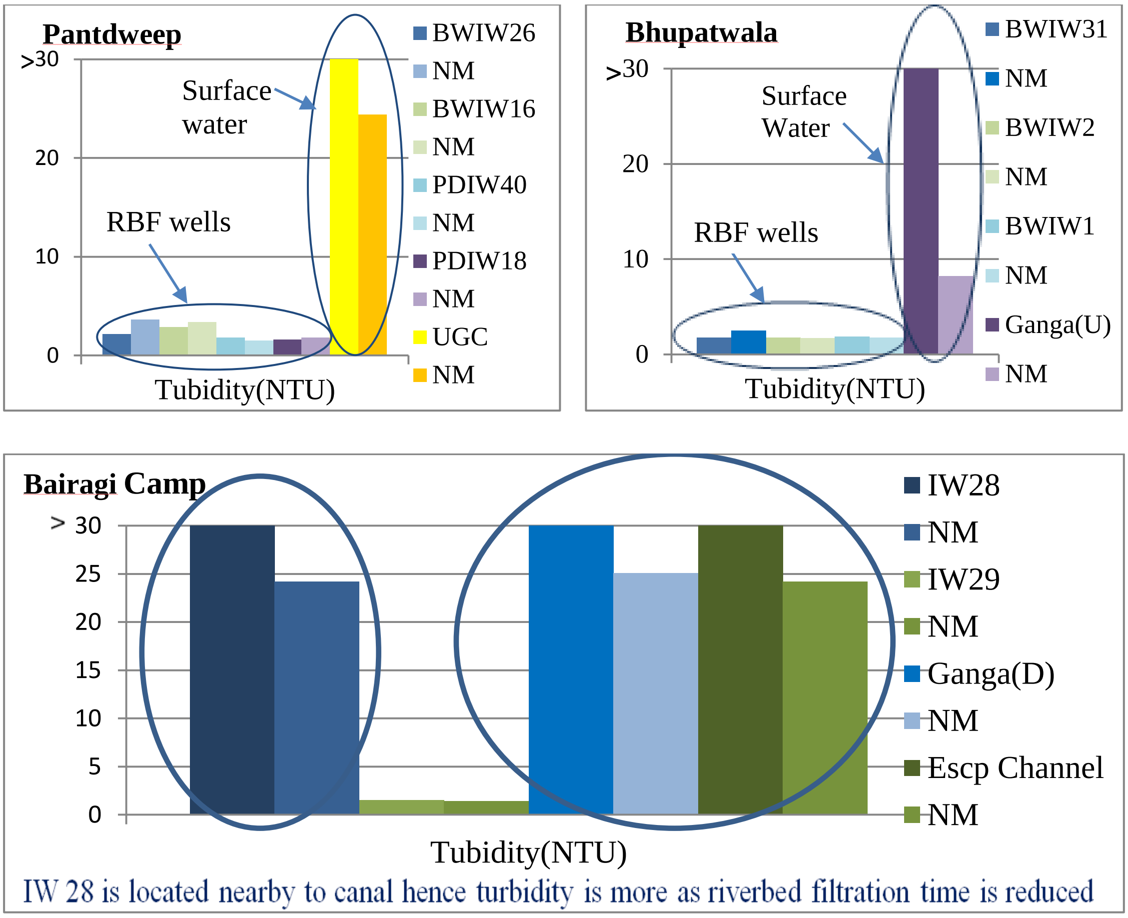

Figure 4. Turbidity (NTU) in river Ganga and Pumping wells.

Electrical Conductivity itself is not a human or aquatic health concern, but because it is easily measured, it can serve as an indicator of other water quality problems. Water with high mineral content tends to have higher conductivity, which is a general indication of high dissolved solid concentration of the water (Mumtazuddin et al, 2012). The Electrical Conductivity for RBF wells ranges from 700µS/cm to 400µS/cm whereas EC values for canal and Ganga River is 200µS/cm indicating RBF wells have high mineral content compared to canal/river as influenced by already mineralised groundwater(Figure 5).

Total dissolved solids (TDS) level in RBF wells, canal and river Ganga is well below the acceptable limit of 500 mg/L as per Indian Standards (IS 10500). The concentration of $HCO3^-$ and TDS in RBF wells and groundwater is high due to geogenic sources as TDS refer mainly to inorganic substances that are dissolved in water. The effects of TDS on drinking water quality depend on the levels of its individual components; excessive hardness, taste, mineral depositions and corrosion are common properties of highly mineralized water (Figure 5).

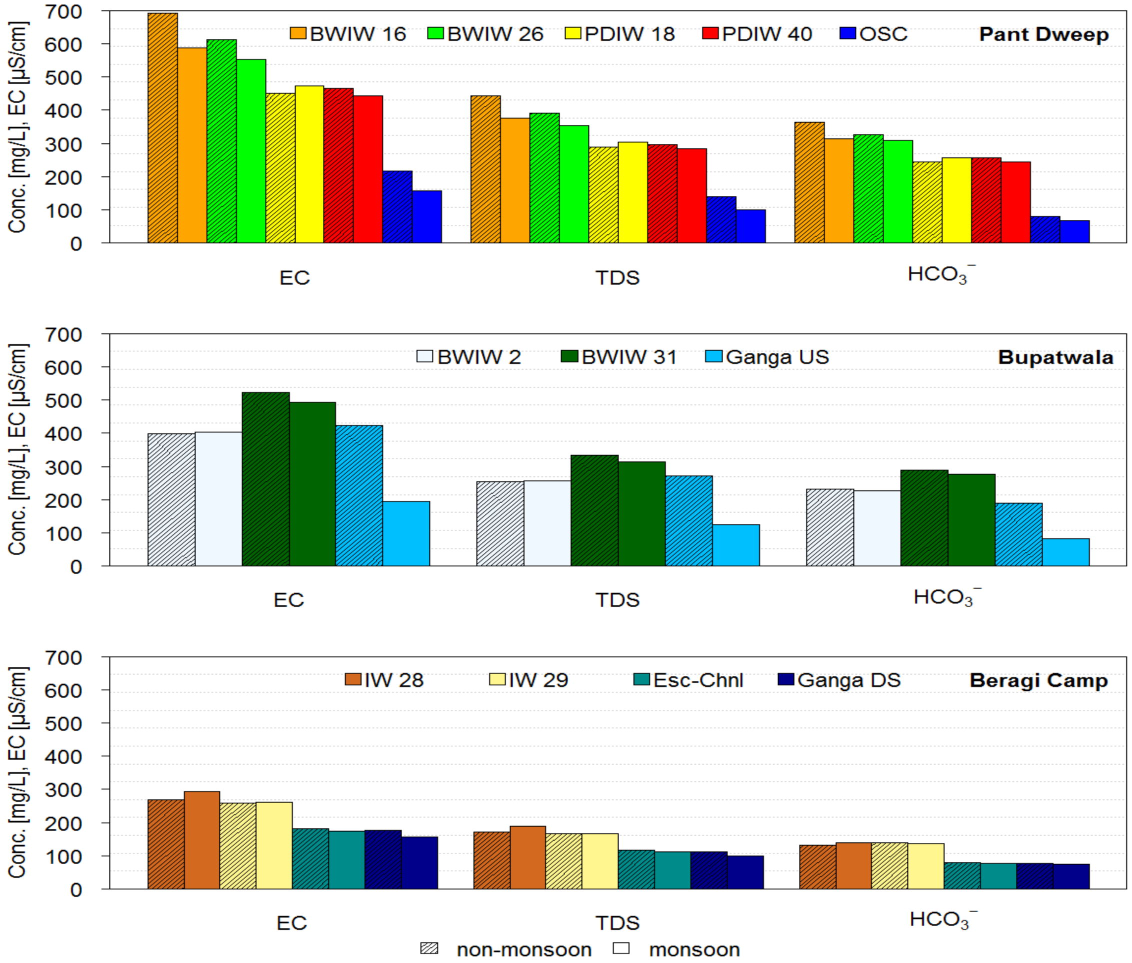

Figure5. River water quality and water quality of Pumping wells regarding electrical conductivity (EC), total dissolved solids (TDS) and bicarbonate (HCO_3^-)

The count of biological parameters, viz. **Total coliform** and **Feacal coliform**, although found to be removed considerably in the extracted water, the count still remained above the acceptable limit, for both non-monsoon and monsoon periods. The percent removal of coliform varied between 78% and 83% for Total coliform and between 65% and 85% for Feacal coliform in comparison to the quality of groundwater for both the non-monsoon and the monsoon periods (Table 2).

Table 2. Min-Max and Mean ± Std count of Total Coliform and Feacal Coliform for Non-Monsoon and Monsoon period

	River and Canal water				Extracted water (RBF wells)				Groundwater(Open well)				Accept-able limit (IS:10500)
	Non-monsoon		Monsoon		Non-Monsoon		Monsoon		Non-Monsoon		Monsoon		
	(Min.-Max.)	(Mean±Std)	(Min.-Max.)	(Mean±Std.)	(Min.-Max.)	(Mean±Std.)	(Min.-Max.)	(Mean±Std.)	(Min.-Max.)	(Mean±Std)	(Min.-Max.)	(Mean±Std)	
TC (MPN/100 mL)	28-2400	897.625 ±1045.27	1000-2400	1614.29 ±735.82	64-1305	374.27 ±284.84	9.20-2400	416.7 ±524.66	1100-2400	2140 ±581.38	1100-2400	1966.67 ±750.56	Must not be detectable
FC (MPN/100 mL)	43-2400	686 ±1004.17	93-2400	1006.63 ±1160.3	3-498	164.45 ±162.76	6.75-2400	570.21 ±698.35	150-2400	1120 ±1047.07	75-2400	1625 ±1342.34	Must not be detectable

***** TC- Total Coliform, FC- Feacal Coliform

RESULTS OF WATER QUALITY ANALYSIS

- During non-monsoon and monsoon season the extracted water gets mineralized during the sub-surface passage through the aquifer, as illustrated by the increasing concentrations of major ions within each well sample.
- The longer the water is held up in the aquifer the more the concentration of Na^+, Ca^{2+}, K^+ and Mg^{2+} increases.
- Ca^{2+} concentration is high in Bhupatwala and Pantdweep as influenced by already mineralized groundwater whereas Bairagi camp has low Ca^{2+} concentration due to its near proximity to canal or surface water.
- The nitrate and sulphate concentration for each well is below the recommended guideline value (WHO, 2011) of 50 mg/L and 500 mg/L respectively.
- Ferrous and Manganese are essential dietary element present in water and according to WHO(2011) the recommended health based limit values for <u>Fe^{2+} and Mn^{2+} are 2 mg/L and 0.4 mg/L</u>, respectively. All RBF (pumping) wells except PW28 shows Fe^{2+} and Mn^{2+} concentration below recommended health limit.
- Turbidity of Ganga River (upstream and downstream of Bhimgoda barrage) is <u>2 to 15 times more turbid in monsoon season</u> due to high flow velocities, high runoff and erosion of soil and riverbed materials respectively.
- Turbidity of the abstracted water is below the Indian Standard limit of 5 NTU (IS 10500, 2012) during monsoon and non-monsoon.
- Electrical conductivity (EC), total dissolved solids (TDS) and bicarbonate (HCO_3^-) of all RBF (pumping) wells is under the allowable limits.

CONCLUSION

This paper highlights that the physicochemical and microbiological characteristics of the produced water from pumping (RBF) wells, after getting filtered through riverbed, subsurface passage and mixing with groundwater are better than the allowable standards for drinking purposes hence proving the effectiveness of RBF technique for potable water supply and management in Haridwar. RBF setup in Haridwar was found to be efficient in removal of turbidity whereas the biological parameters exceeded the acceptable and permissible limits in the present analysis. Therefore, a post-treatment of the extracted water, particularly disinfection of the biological parameters, would be necessary before supply of water to users for drinking purposes. As post-treatment, Uttarakhand Jal Sansthan (UJS) who is responsible for domestic water supply has been using the appropriate doses of *Sodium hypochlorite* (NaClO) solution as disinfectant to remove biological contents in the extracted water.

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